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AUTOMATED WELDING OF ROTARY FORGE HAMMERS

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13. ABSTRACT *(Maximum 200 words)*

The process development and implementation of an automated welding system used for repairing rotary forge hammers was performed by Benet Laboratories under a Manufacturing Methods and Technology project at Watervliet Arsenal. Two welding technologies were evaluated in the project, automated flux-cored wire-feed welding by the metal inert gas (MIG) process and powdered metal feed welding by the plasma transferred arc (PTA) process.

Initially, two development contracts were established and executed to determine the feasibility of and welding parameters necessary for hammer repair. Both contracts involved welding representative test samples to determine the optimum parameters for deposition rate and quality, and finally utilizing these parameters to weld-overlay actual rotary forge hammers. The hammers were then returned to Watervliet Arsenal for testing in production runs.

Based on encouraging results generated during the project, the flux-cored wire-feed welding method has been implemented at the Arsenal and is the current production welding method used for hammer repair and restoration.

14. SUBJECT TERMS

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INTRODUCTION

Watervliet Arsenal employs a GFM-55 rotary forge machine, shown in Figure 1, to hot-work *preforms* (tubular-shaped, constant inner diameter (ID)-outer diameter (OD) thick-walled cylinders as in Figure 2) into near-net shape gun tube forgings (Figure 3). The rotary forge utilizes four heavy (approximately 1000 pounds each) steel hammers as seen schematically in Figure 4. These hammers are set 90 degrees apart from one another to accomplish the forging process. Because the preforms must be heated to their forging temperature range of approximately 1800° to 1900°F for the GFM operation, the forging face of each hammer must be surfaced with a high temperature, superalloy hardfacing deposit. In addition to the hardfacing layer, an underlying layer of *buffer* material must first be deposited to minimize cracking caused by incompatibility between the hammer's base material and the hardfacing material. These deposits exhibit a finite service life that is dictated by the maximum amount of deformation, shown in Figure 5, allowed during the forging operations. Once the hardfacing has deformed past this amount, the hammer surfaces must be completely restored (both hardfacing and buffer material) before they are returned to service. The welding operations are extremely time-consuming, operator-dependent processes which lack any predictable deposit quality.

This project was generated to develop alternate forms of filler materials for the hammer repair process and to utilize existing welding technologies in an attempt to reduce welding time and increase weld deposit quality and uniformity.

STATEMENT OF THE PROBLEM

The established method used to weld/hardface the rotary forging hammers with a high temperature, wear resistant superalloy is a time-consuming, manual process that is solely dependent on operator experience. This often results in a nonuniform quality in the hammer overlay. The hardfacing alloy (Udimet 520) and buffer alloy (Weldmold 673) are available only in 0.5-inch bar stock in the form of stick electrodes.

PROPOSED SOLUTION

The proposed solution is to ensure a uniform quality in the weld overlay, as well as reduce the time necessary for welding. Automation of the process can be achieved with equipment and technologies presently available. However, in order to take advantage of these technologies, it is necessary to have the equivalent Udimet 520 and Weldmold 673 alloys, hereafter referred to as U520 and W673, available in flux-core metal wire and/or powdered metal forms rather than stick electrode form. This project addresses the application of existing technologies to manufacture these metal forms for automation.

PROJECT OBJECTIVES

Project objectives include the following:

1. To develop alternate forms of filler materials for utilization in rotary forge hammer repair/restoration.

2. To automate the welding process utilizing U520 and W673 flux-cored welding wires. This task will take advantage of existing equipment at Watervliet Arsenal.

3. To develop the procedure and parameters for automated welding of the hammers using a powdered metal feed system. This effort will establish the foundation for a future welding technology, which has the potential for even greater weld deposit uniformity and reduced welding times (and associated labor costs.)

PROCEDURE

This project was performed according to the following procedure:

1. Specification and execution of two developmental contracts for the welding materials/techniques of interest (wire feed and powder feed). These contracts required that welding process/parameter development be performed on supplied test samples to optimize results, and then the parameters be employed on the actual forging hammers.

2. Material analysis of test specimens welded in part 1.

3. In-process testing and analysis of actual forging hammers welded in part 1.

4. Implementation of flux-cored wire feed system using gas metal arc-welding (GMAW) methods and existing equipment.

DEVELOPMENT OF SPECIFICATIONS

Two similar sets of contractor specifications were formulated for the welding techniques being investigated. The major requirements listed in these specifications follow.

Requirements for Powdered Metal Feed Method

Benet Laboratories Material Requirements

1. Two types of test specimens would be provided:

   - 4 x 4 x 1-inch annealed 4140 blanks (Figure 6a)
     Quantity: 6

   - 4 x 5 x 8-inch annealed 4140 blanks (Figure 6b)
     Quantity: 3

Note: 5 x 8-inch surface of blanks would have a centrally located weld prep (Figure 7) machined into the surface; dimensions of the weld prep would be 3 x 6 x 1/2-inch.

2. Five forging hammers would be provided as follows:

Hammers shown in Figure 8 supplied to the contractor would have weld prep arc-air gouged into the surface. Approximate dimensions of the weld prep would be 22 x 4 x 1/2-inch. Hammer material would be Finkl FX Xtra, composition of which is shown in Table I.

Table 1. Chemical Composition of Hammer Material
(Weight Percent)

Element	Chemistry
Carbon	0.55
Silicon	0.25
Nickel	1.00
Chromium	1.00
Manganese	0.85
Molybdenum	0.40
Iron	Balance

Contractor Requirements (General)

The general contractor requirements include:

1. An automated welding process selected by the contractor would be used to process all specimens. This process would be integrated with powdered filler metal to perform welding on all specimens.

2. All specimens should receive the following precautionary treatments to deter cracking in the hammers:

- A preheat and a postheat at a temperature determined by the contractor, and approved by Benet, in order to optimize the procedure.

- Stress relief of the specimens to be determined by experimentation on the part of the contractor.

- Where multiple pass welds are required, interpass peening would also be required.

3. Interim progress reports would be submitted on a monthly basis to Watervliet Arsenal listing parameters used in each welding process, abnormalities experienced, and overall assessment of the procedure.

4. Powder particle size would be determined by the contractor and approved by Benet.

5. A sampling of powder would be supplied to Benet for chemical analysis.

6. A final technical report would be due at the conclusion of the contract stating all welding and heat treating parameters and procedures utilized, and summary of results.

7. Dye penetrant testing would be performed by the contractor. Surface defects in excess of 0.25 inch would be unacceptable.

Contractor Requirements (Detailed)

The detailed contractor requirements include:

1. Three of the 4 x 4 x 1-inch test specimens would be welded using a powdered filler metal with a W673 composition or that specified in AMS 5388. Chemical composition of the W673 filler metal is listed below in Table 2. The weld deposit would consist of a minimum of three weld passes on top of one another to aid in determining correct chemical composition.

Table 2. Nominal Chemical Composition of W673 Filler Metal
(Weight Percent)

Element	Chemistry
Carbon	0.10
Chromium	15.00
Molybdenum	15.00
Tungsten	4.00
Nickel	Balance

2. The remaining three 4 x 4 x 1-inch test specimens would be welded using a powdered filler metal with a U520 composition. The chemical composition of the U520 filler metal for these specimens is listed in Table 3. Again, a minimum of three passes would be required one on top of the other.

Table 3. Nominal Chemical Composition of U520 Filler Metal
(Weight Percent)

Element	Chemistry
Carbon	0.05
Chromium	19.00
Molybdenum	6.00
Tungsten	1.00
Cobalt	12.00
Titanium	3.00
Aluminum	2.00
Iron	1.00
Nickel	Balance

3. The three 4 x 5 x 8-inch test specimens would be welded using the procedure described below:

- A 3 x 6 x 3/8-inch thick weld deposit of W673 would be produced in the weld prep listed previously.

- A second weld deposit of equal dimensions would be produced on top of the deposit specified immediately above. The filler material would be U520.

4. One hammer would be welded accordingly:

- A 3/8-inch thick weld deposit of W673 would be produced in the hammer's weld prep. Multiple passes would be permissible.

- A second deposit would be produced over the first using U520. This would also be 3/8-inch thick with multiple passes permissible. Then the hammer would be destroyed in testing at Watervliet Arsenal to determine the overall quality of the procedure and weld.

5. The remaining four hammers would be welded using a procedure determined by Benet based on the results obtained from the destroyed hammer. Should the destroyed hammer have been welded acceptably, the remaining hammers would be welded using the same procedure.

6. Welding parameters to be reported by the contractor include:

- Dimensions of single weld pass
- Number of passes to complete prepped hammer
- Temperatures involved in preheat, postheat, and stress relief
- Rate of deposition of weld material
- Equipment used
- Other pertinent data
- Powder composition
- Particle size
- Weld energy parameters

Quality Assurance Analyses

The following would be performed at Watervliet Arsenal:

1. Ultrasonic testing of the hammers for detection of unacceptable degrees of shrinkage, cracking in the weld region, and underbead cracking.

2. Dye penetrant testing of hammers for detection of surface flaws in the weld region.

3. Chemical analyses of welds on test specimens based on limits previously specified.

4. Metallographic examination to determine the weld quality, including microcracking, inclusion level, etc.

Requirements for Wire Feed Method

The specifications for this welding method are virtually identical to those listed the powder feed section. The exceptions primarily involve wire characteristics (i.e., wire diameter and composition) rather than powder characteristics.

RESULTS

Work Conducted Under Powder Feed Method

A contract was awarded to Metallurgical Industries, Inc., Tinton Falls, NJ, to perform the required welding. The first contractual requirement was to utilize the selected welding process, in this case the plasma transferred arc (PTA) process, to prepare two types of test specimens. A typical PTA torch is illustrated schematically in Figure 9. Inert gas flows in three separate gas paths. The argon center gas flows through the torch around the negative tungsten electrode; it is ionized as it passes the electrode tip and forms a plasma jet as it issues from the nozzle orifice. Another inert gas stream, helium in this case, carries the metal powder from a powder feeder to the torch and directs it into the plasma external to the nozzle. The third gas stream of argon flows out of a gas diffuser around the periphery of the nozzle. It provides shielding for the powder transported through the plasma column and for the weld deposit formed on the substrate. The shield gas flow rate is generally much higher than the others since it must protect a large surface area. The powder and center gas flow rates affect penetration, powder flow, and other variables of the process.

The PTA powder feed welding technique required that a significant amount of material and process development be performed on the test samples prior to application to the forging hammers.

Test Specimens

In accordance with the specifications, two specimen types were welded. One specimen type consisted of annealed 4140 steel plates, nominally 4 x 4 x 1-inch, to be weld overlaid with a minimum of three weld passes one on top of another. Three specimens were to be welded using W673 and three using U520. Because of the relatively poor welding characteristics of the W673 powder used, new powder was obtained prior to starting on the second specimen type. Compositions of all powders used in this project are shown below. The second specimen type consisted of annealed 4140 steel plates, nominally 4 x 5 x 8 inches, each having a centrally located weld prep approximately 3 x 6 x 1/2-inch, machined into the 5 x 8-inch surface. Three such specimens were to be prepared by first depositing a 3/8-inch layer of W673 in the 3 x 8-inch weld prep, then weld overlaying U520 to the same dimensions over the first deposit.

Preparation of 4 x 4 x 1-Inch Test Specimens

Actual chemical compositions and particle mesh sizes of powder filler metals used on the 4 x 4 x 1-inch test specimens are shown in Tables 4 and 5, respectively.

Table 4. Actual Chemical Compositions of W673 and U520 Used on 4 x 4 x 1-Inch Test Specimens (Weight Percent)

Element	W673	U520
Carbon	0.06	0.076
Chromium	16.46	19.19
Molybdenum	17.46	6.03
Tungsten	4.66	1.02
Iron	6.00	--
Cobalt	1.24	12.01
Silicon	0.62	0.02
Vanadium	0.37	--
Titanium	--	2.85
Aluminum	--	2.16
Nickel	Balance	Balance

Table 5. Particle Mesh Sizes of Powder Filler Metals Used on 4 x 4 x 1-Inch Test Specimens

Alloy	Mesh Size
W673	-0/+325
U520	-60/+325

Test specimens were identified by letter codes A through F stamped into the steel. Surface preparation consisted of grinding one 4 x 4-inch surface and the sides to clean, bright metal prior to placement in the preheat furnace. Except for specimen F, all were wire brushed upon removal from the furnace to remove any oxide or debris. Specimen F was ground rather than wire brushed after removal.

Welding of 4 x 4 x 1-Inch Test Specimens

As previously stated, the welding process selected was PTA wear surfacing. Equipment and welding details are:

- System - Linde PSM-22
- Torch - Standard Linde PT-9, H.D.

- Powder Delivery - Two powder ports perpendicular to the direction of travel

An overview of the equipment setup is shown in Figure 10. Deposit characteristics are described below.

- Specimen A (W673)

Upon completion of the third pass in the second layer, the deposit separated from the substrate. Welding was stopped at this point. All deposits had an extremely poor appearance, with oxide and slag, that did not wet preceding deposits very well. Weld deposits (passes) were approximately 0.94-inch wide by 0.18-inch thick.

- Specimen B (W673)

Characteristics were essentially the same as specimen A, except that separation of the deposit from the substrate was not noticed until completion of the third layer. First-layer deposits were approximately 0.94-inch wide by 0.18-inch thick; second and third layers, 0.80-inch wide by 0.12-inch thick.

- Specimen C (W673)

Characteristics were essentially the same as specimen A, except there was no observed separation of the deposit from the substrate. Weld deposits were approximately 0.80-inch wide by 0.12-inch thick.

- Specimens D and E (U520)

These specimens experienced good flow and good wetting of the substrate and of preceding deposits. No porosity indications existed, and a light oxide layer formed was easily wire brushed off. Weld deposits were approximately 0.80-inch wide by 0.14-inch thick.

- Specimen F (W673)

Characteristics were essentially the same as specimen A, except there was no observed separation of the deposit from the substrate. First-layer deposits were approximately 0.76-inch wide by 0.12-inch thick; second and third layers were 0.72-inch wide by 0.135-inch thick.

Specific welding parameters associated with specimen A are outlined below:

- Filler metals - W673
- Current - 190 amps
- Arc voltage - 26 volts
- Powder rate - 43 grams/minute
- Travel speed - 3.5 inches/minute
- Oscillation - 3/4 to 7/8 inch width

  - 32 cycles/minute speed

  - no dwell

- Gas settings:

  Powder - 15 cubic feet per hour (cfh) helium

  Shield - 50 cfh argon

  Center - 7 cfh argon

- Thermal history:

  Preheat - 700°F

  Interpass - 500° to 700°F

  Postweld - returned to furnace at 700°F for 2 hours, then increased to 900°F for 45 hours and furnace cooled

Welding Progression

First and second layers of weld metal were deposited parallel to one another. Individual deposits were wire brushed to remove oxide and slag before proceeding with welding. The first layer was peened before proceeding to depositing the second layer. Test sample welding results are summarized below in Table 6.

Table 6. Test Sample Welding Results

Code	Overlay	Description
A	W673	Deposit separated from substrate during third pass on second layer
B	W673	Separation between deposit and substrate noted adjacent to final pass on third layer
C	W673	Satisfactory three-layer deposit; highest preheat and thinner layers used
D	U520	Satisfactory three-layer deposit; minor depressions at weld stop point
E	U520	Same as D
F	W673	Satisfactory three-layer deposit; stress relieved 1100°F

Preparation of 4 x 5 x 8-Inch Test Specimens

The second type of three test specimens, annealed 4140 steel blanks, nominally 4 x 5 x 8-inches with a 3 x 6 x 1/2-inch weld prep, was welded using a second lot of W673 powder (W673/2), composition shown in Table 7, and the same U520 used for the previous test specimens.

Table 7. Chemical Composition of W673/2 Used on 4 x 5 x 8-Inch Specimens (Weight Percent)

Element	Chemistry
Carbon	0.06
Chromium	16.24
Molybdenum	16.65
Tungsten	4.62
Iron	6.55
Cobalt	0.70
Silicon	0.74
Vanadium	0.28
Nickel	Balance

The mesh size of the W673/2 was -80/+325.

Surface preparation consisted of degreasing the blanks with acetone prior to preheating, then grinding the weld prep area to clean, bright metal immediately upon removal from the furnace.

Welding of 4 x 5 x 8-Inch Test Specimens

Specific welding parameters associated with the 4 x 5 x 8-inch test specimens are:

1. Lower layer:

- Material - W673/2
- No. of layers - 3
- Deposit thickness - 3/8 inch
- Current - 185 amps
- Arc voltage - 28 volts
- Powder rate - 35 grams/minute
- Travel speed - 3.5 inches/minute

- Oscillation - 3/4 to 7/8 inch width

  - 32 cycles/minute speed

  - approximately 1/2 second dwell on outer edges

- Gas settings:

  Powder - 15 cfh helium

  Shield - 50 cfh argon

  Center - 7 cfh argon

- Thermal history:

  Preheat - 900°F

  Interpass - 800° to 900°F

2. Upper layer:

- Material - U520
- No. of layers - 3
- Deposit thickness - 3/8 inch
- Current - 175 amps
- Arc voltage - 28 volts
- Powder rate - 27 grams/minute
- Travel speed - 3.5 inches/minute
- Oscillation - 5/8 to 3/4 inch width

  - 32 cycles/minute speed

  - approximately 1/2 second dwell on outer edges

- Gas settings:

  Powder - 15 cfh helium

  Shield - 50 cfh argon

  Center - 7 cfh argon

- Thermal history:

Starting temperature	- 700°F
Interpass	- 600° to 700°F
Postweld	- returned to furnace at 1100°F, held 2 hours, then furnace-cooled to ambient

Welding Progression

In all cases, travel was delayed manually at the start of welding until the weld material was visually observed to wet the weld prep wall. An approximate one-half second dwell was used on the outside edge of the beads adjoining the steel within the weld prep in order to ensure wetting between the steel and deposit.

- Specimen A1

The first layer was run in the direction of the long dimension of the weld prep. Because of the problem encountered with the first set of specimens (flat plates), each layer of weld was applied in a direction perpendicular to the preceding layer. Each layer was peened before proceeding to the next layer. Small crater cracks were observed at the ends of some deposits, but they did not extend back into the deposit and they were apparently eliminated with the next deposit layer. Weld deposits were approximately 7/8 to 1-inch wide for W673/2, and 3/4 to 7/8-inch wide for U520. Deposit layers were approximately 0.125 to 0.150-inch thick.

- Specimen B1

Weld progression was the same as specimen A1, except that all deposits were applied in the same direction as the first layer, not alternating layers normal to each other. Crater cracks were virtually eliminated by manually downsloping the current amperage at the end of each weld bead.

- Specimen C1

Weld progression was the same as specimen B1, except the width of the final U520 deposit was 5/8 to 3/4-inch wide.

In all cases, the final bead in each layer had the oscillation width increased or decreased as required to complete coverage.

As previously stated, the W673 material used was not the same as that used for the first set of test specimens, although its chemical composition was nominally the same. The change was made to improve deposit characteristics.

It was found that weld layers could be deposited parallel to one another without the separation problems encountered with the first set of test specimens. Some crater cracks that developed at the weld stop points on the first specimen welded were eliminated on subsequent specimens by manually downsloping the welding current amperage at the end of each weld. It appears that the preheat, interpass, and postweld temperatures used for these test specimens may be used as a starting point for welding of the forging hammers.

Deposit layers were applied perpendicular to one another in an attempt to evenly distribute the stresses on both the block and the weldment. It is felt that on a larger blank or part, distortion (bowing) of the base metal will not be a problem (due to greater mass), and deposits can be made parallel to one another. All test samples exhibited very smooth, clean weld deposits as shown in Figure 11.

Forging Hammers

Repair of the hammers required that a preheat chamber be constructed. Once the chamber was assembled, the initial forging hammers were rebuilt. The equipment setup is shown in Figures 12a and 12b. A furnace was used to pre/postheat the hammers in the welding process in an attempt to minimize crack susceptibility. This furnace rests on a positioning table with Y-axis and tilt motion. Powder is fed into the PTA torch from a storage container. The powder is forced via gas flow through two tubes that connect to the torch. The entire torch/powder container setup is mounted to a traverse positioner (X-axis motion). Also visible in Figure 12 is the forging hammer, which has a weld prep machined into its forging face that the powdered metal will fill during the PTA process. This process has been demonstrated to yield a very small dilution zone (zone in material that is a mixed chemistry resulting from the molten filler metal solidifying in combination with the molten base metal), which is advantageous to a material's mechanical properties.

The rebuilding process consisted of weld depositing a 3/8--inch thick layer of W673 in the hammers' weld prep, using multiple passes as required, followed by deposition of a 3/8-inch thick layer of U520 on top of the first material, again using multiple passes as required.

Welding of Forging Hammers

Typical welding parameters used on the hammers are given below. The initial hammer welded was sent to Watervliet Arsenal for destructive testing and evaluation. The remaining four forging hammers were welded with no changes to the welding procedure.

1. Bottom deposit:

   - Material - W673/2
   - No. of layers - 3
   - Deposit thickness - 1/4 to 5/16 inch
   - Current - 100 to 200 amps
   - Arc voltage - 28 volts
   - Powder rate: - 39 grams/minute
   - Travel speed - 2.8 inches/minute
   - Oscillation - 1 to 1-1/4 inches width
     - 22 cycles/minute speed
     - approximately 1/2 second dwell on outer edges

- Gas settings:

Powder	- 15 cfh helium
Shield	- 50 cfh argon
Center	- 7 cfh argon

- Thermal history:

Preheat	- 900°F
Interpass	- 800° to 900°F

2. Top deposit:

• Material	- U520
• No. of layers	- 3
• Deposit thickness	- 1/4 to 5/16 inch
• Current	- 160 to 190 amps
• Arc voltage	- 26 volts
• Powder rate	- 32 grams/minute
• Travel speed	- 3 inches/minute
• Oscillation	- 1 to 1-1/4 inches width
	- 22 cycles/minute speed
	- approximately 1/2 second dwell on outer edges

- Gas settings:

Powder	- 15 cfh helium
Shield	- 50 cfh argon
Center	- 7 cfh argon

- Thermal history:

Starting temperature	- 900°F
Interpass	- 800° to 900°F
Postweld	- furnace cool

Welding Progression

In rebuilding the first of the four remaining hammers, hammer no. 2, the cooling occurred between welding passes. Apparently because the weld prep area was larger, the interpass temperature was dropping more between weld passes. Some cracking of the U520 occurred in the second layer as a result. Welding was stopped and two passes with cracks were gouged out and subsequently repaired while finishing the U520 weld buildup. In rebuilding this hammer, the material designated W673/2 was used up. The remaining three hammers were weld repaired with W673/3, a third lot of powdered filler metal. Based on experience with this hammer, some heating and welding parameter changes were necessary. Also initiated was the use of gas torch heating between layers to raise the interpass temperature. The modified welding parameters were applied to the remaining hammers.

Upon completion of hammer no. 3, several cracks in the U520 were again observed. On the short area of the weld prep (thick section of the hammer), three layers of U520 were gouged out to repair a deep crack. On the larger weld prep area, two surface cracks were repaired in the U520. Hammer no. 4 was welded in two stages, depositing the W673 one day and the U520 the following day. After depositing the W673, the hammer was maintained at 600°F overnight and brought up to 932°F prior to beginning welding with U520. Several small surface cracks in the U520 were repaired during the process of building up the layer.

Hammer no. 5 contained cracks in the weld prep area that appeared to be in a previous weld repair, and to run through it to the steel. In retrospect, these should have been gouged out and repaired prior to starting the rebuilding process.

During application of the W673, an attempt was made to *heal* the cracks that were of major proportions. This was unsuccessful. After cooling, two large cracks were gouged out to the base material and weld repaired by the GMAW process using a welding rod with a composition equivalent to W673. The hammer was then reheated to 932°F and the U520 applied.

Upon return to Watervliet Arsenal, the as-welded hammers shown in Figure 13 were finish machined and installed in the rotary forge for in-process testing. In terms of number of forgings produced prior to necessary replacement, the hammers outperformed conventionally-welded hammers by approximately 10 percent. However, similar problems such as cracking and deformation were experienced.

Work Conducted Under Wire Feed Method

This contract was awarded to and executed by Mark-Five Industries, Inc., Buffalo, NY. Very few problems were encountered during this contract as opposed to the previous contract. Significantly less process/material development work was required during this effort because metal inert gas (MIG) welding, utilizing wire filler material, is a relatively established process. Standard MIG equipment was used to satisfy the contractual requirements.

Test Specimens

The test samples were welded by a simple two-axis welding torch/track assembly. A five-axis, welding torch/part positioning assembly was utilized to process the actual forging hammers. The test samples and forging hammers were all welded using two special purpose flux-cored wire filler materials, Weldmold 673 tubular wire and Weldmold 4637 (Udimet 520 equivalent) tubular wire. The nominal compositions of these wires are given in Table 8.

Table 8. Chemical Compositions of Weldmold 673 and Weldmold 4637 Used on Wire Feed Test Specimens (Weight Percent)

Element	Weldmold 673	Weldmold 4637
Carbon	0.08	0.05
Chromium	15.50	19.00
Molybdenum	16.00	6.00
Tungsten	3.80	1.00
Iron	5.50	--
Cobalt	2.50	12.00
Silicon	1.00	1.60
Manganese	1.00	--
Titanium	--	3.00
Aluminum	--	2.00
Nickel	Balance	Balance

Welding Under Wire Feed Method

After the nominal welding parameters were developed using samples manufactured by the contractor, the parameters were applied to the workpieces supplied by Benet. All workpieces (test samples and forging hammers) were welded using the following conditions:

1. Workpieces were preheated to 600° to 700°F.

2. A minimum of three welding passes was applied to achieve a 3/8-inch buildup for both wires utilized.

3. Weld slag was removed after completion of each pass and the weld surface was peened.

4. Workpieces were maintained at the above temperature range throughout the welding process plus an additional 30 minutes thereafter.

5. As-welded workpieces were dye-penetrant inspected.

6. Workpieces were stress relieved at 1022°F for 4 hours at temperature.

7. Workpieces were furnace cooled over an 8-hour time span.

8. Specific welding parameters used were:

- DC straight polarity via constant potential power source
- 220/225 amps at 25 arc volts
- 75/25 argon/CO_2 gas shielding at 40 cfh
- Weld travel speed at 20 inches/minute
- Step-over index of 5/8 inch
- Weld bead width of 3/4 inch

All test samples were successfully welded (i.e., no cracking) using the techniques/parameters previously listed. The as-welded deposits were relatively rough in finish as shown in Figure 14, but did not exhibit any noticeable flaws.

Five forging hammers were weld repaired, and four of the five were successfully welded and shipped to Watervliet Arsenal after inspection. The last hammer experienced cracking during the weld repair process. A metallurgical analysis was performed on this hammer, and it was determined that the hammer contained pre-existing cracks prior to the welding process. These cracks then proceeded to expand during welding. This hammer was not utilized for in-process testing. The four acceptable hammers were then put into service testing and the results were encouraging. These hammers exhibited an average increase in service life of approximately 20 percent over conventionally-restored hammers, based on number of preforms forged before hammer replacement was necessary.

CONCLUSIONS

1. Both filler metal forms, flux-cored wire and powder, developed in this project are readily available in the required compositions from numerous industrial sources.

2. Both welding processes used to deposit these filler metal forms were successfully automated, and consequently produced deposits faster and with better quality and uniformity than the conventional stick electrode method.

3. The PTA powder feed method produced very clean, smooth weld deposits that reduce postweld machining time.

4. In-process weld cracking susceptibility is strongly dependent on powder filler metal quality.

5. The MIG flux-cored wire feed method is simpler and requires less process development.

6. Both welding methods resulted in an increase in rotary forge hammer life attributed to the advantages listed in conclusion no. 2 above.

EPILOGUE

Based on results generated during this project, a semi-automated, flux-cored wire feed welding system was manufactured and implemented at Watervliet Arsenal. This system was implemented by integrating existing equipment with the developed filler metals. Utilization of the new system has resulted in a significant decrease of approximately 50 percent in welding time required to repair/restore the hammers, as compared to the old stick electrode method. Weld deposit uniformity and quality have also increased due to the automation included in the new process. This has translated into increased service life exhibited by the forging hammers.

Figure 1. GFM-55 rotary forge machine.

Figure 2. Close-up of hot preform entering forging box.

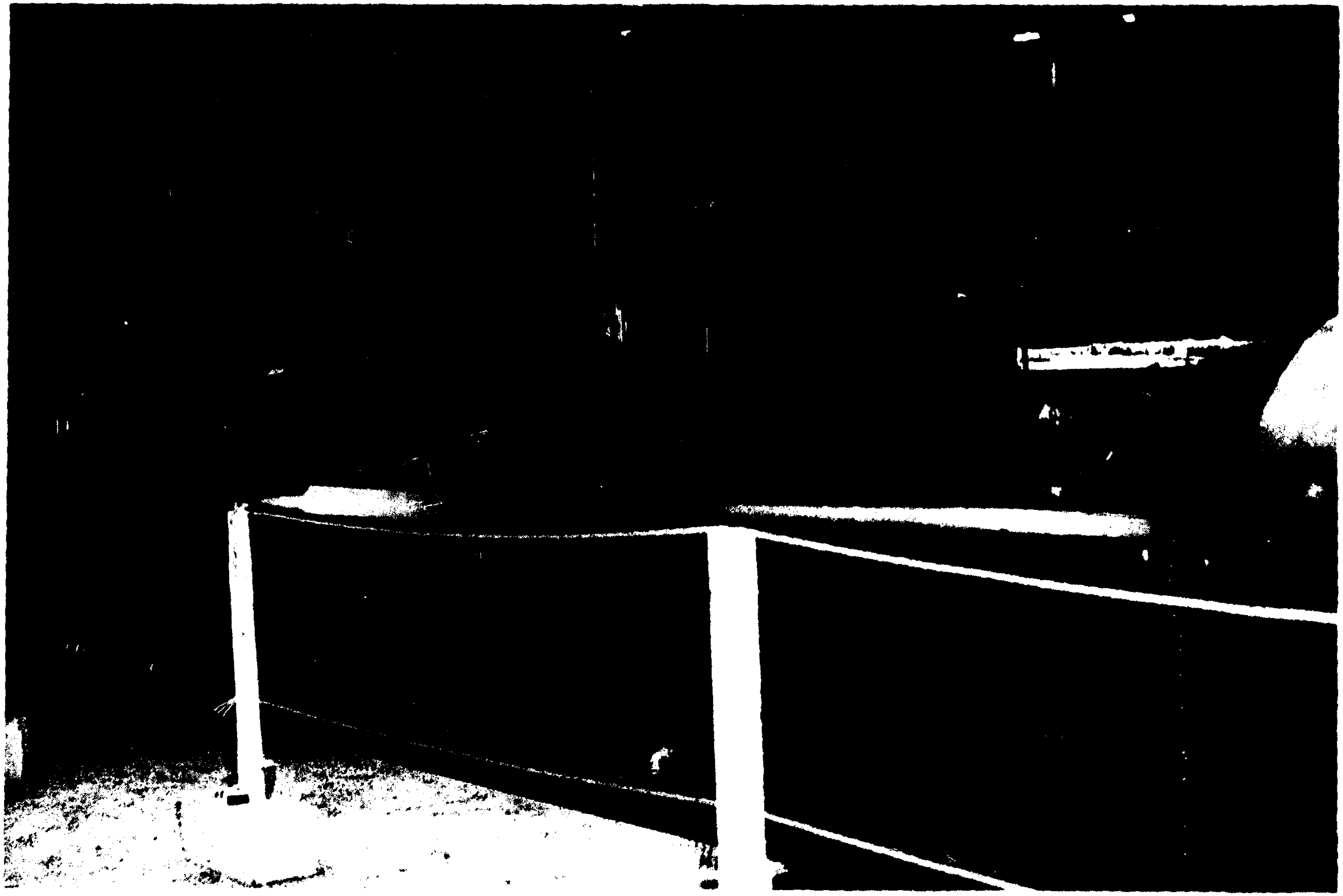

Figure 3. Gun tube forging exiting forging box.

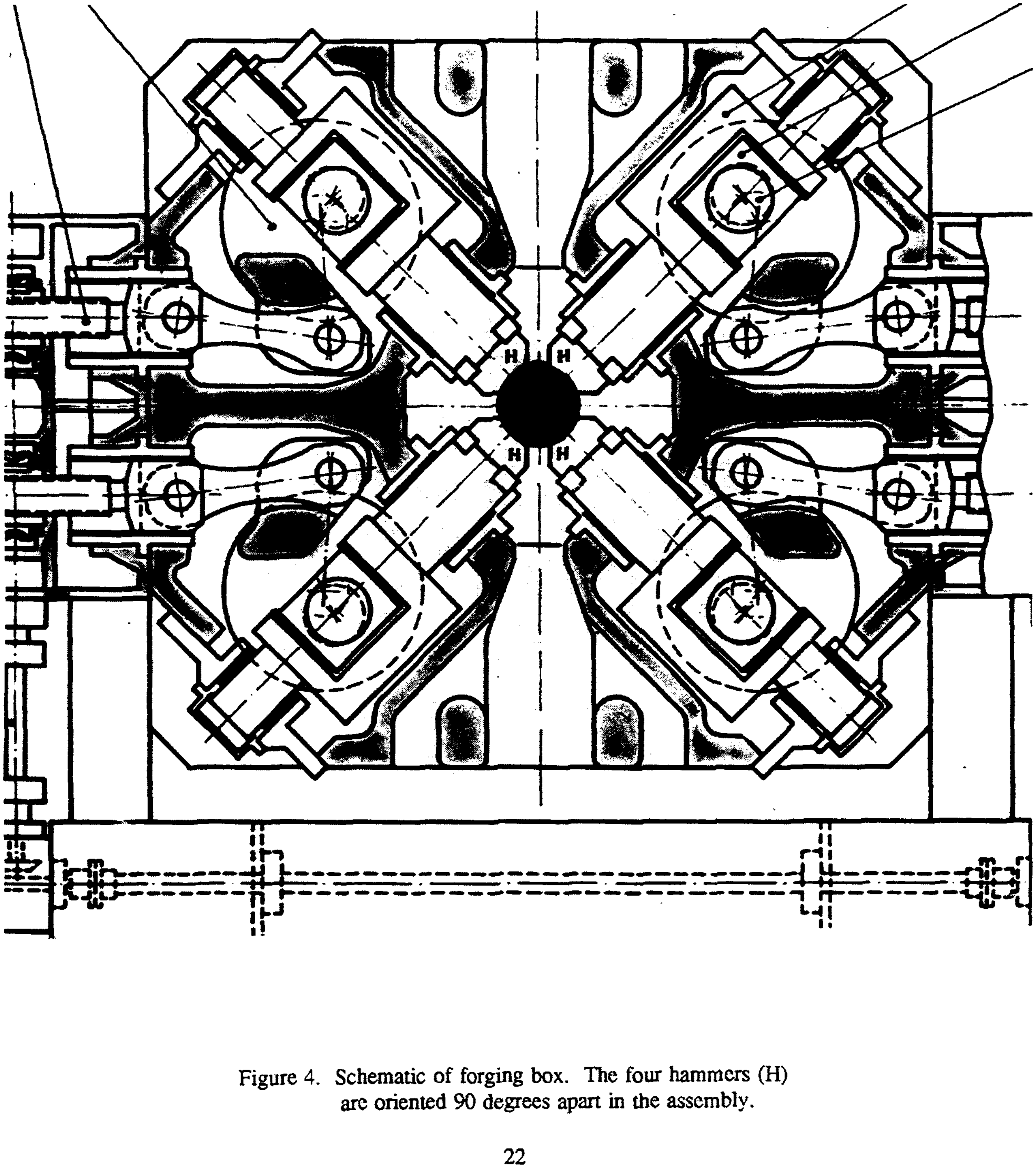

Figure 4. Schematic of forging box. The four hammers (H) are oriented 90 degrees apart in the assembly.

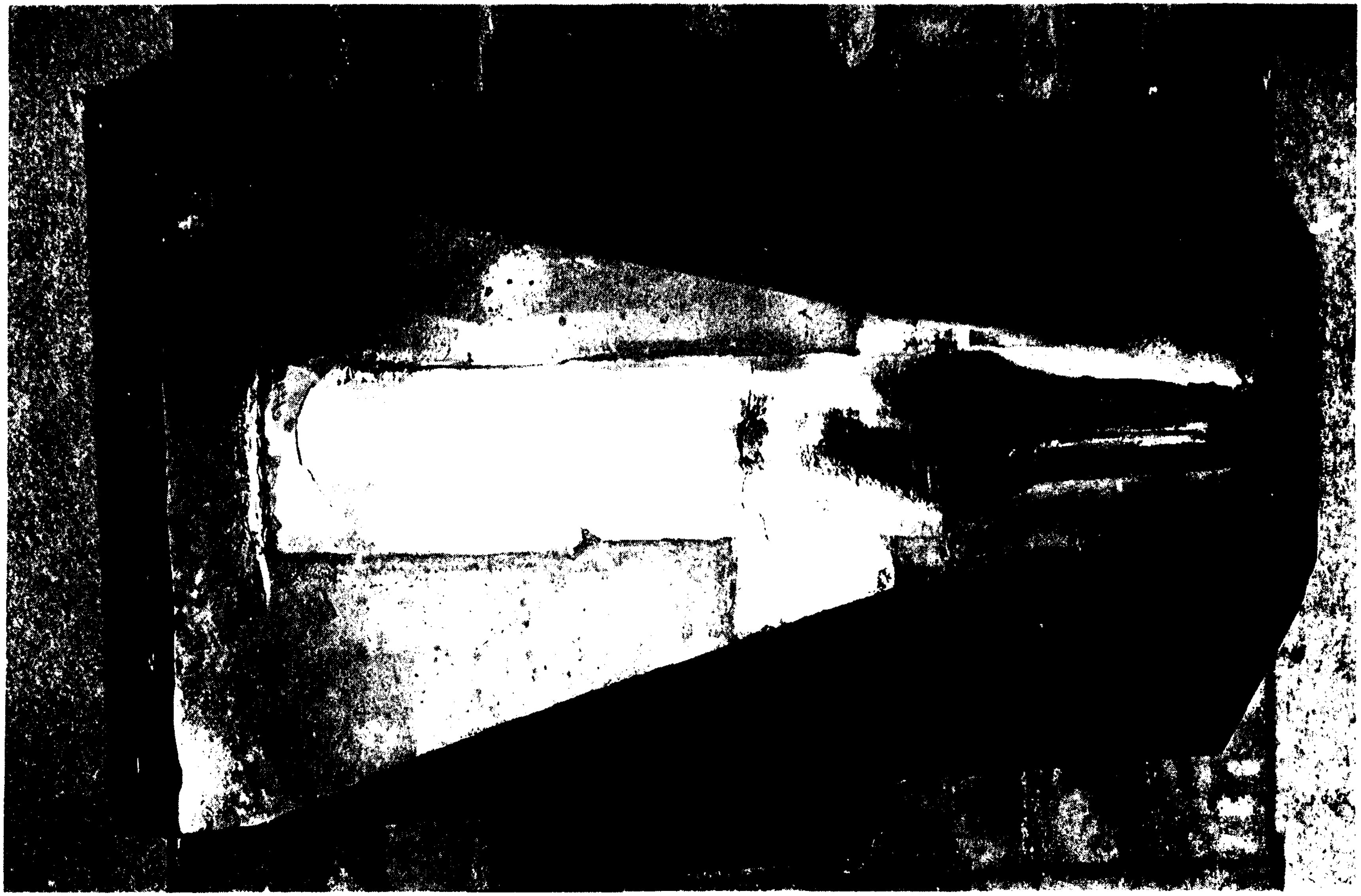

Figure 5. Photograph of forging hammers exhibiting deformation and cracking that resulted from the forging process.

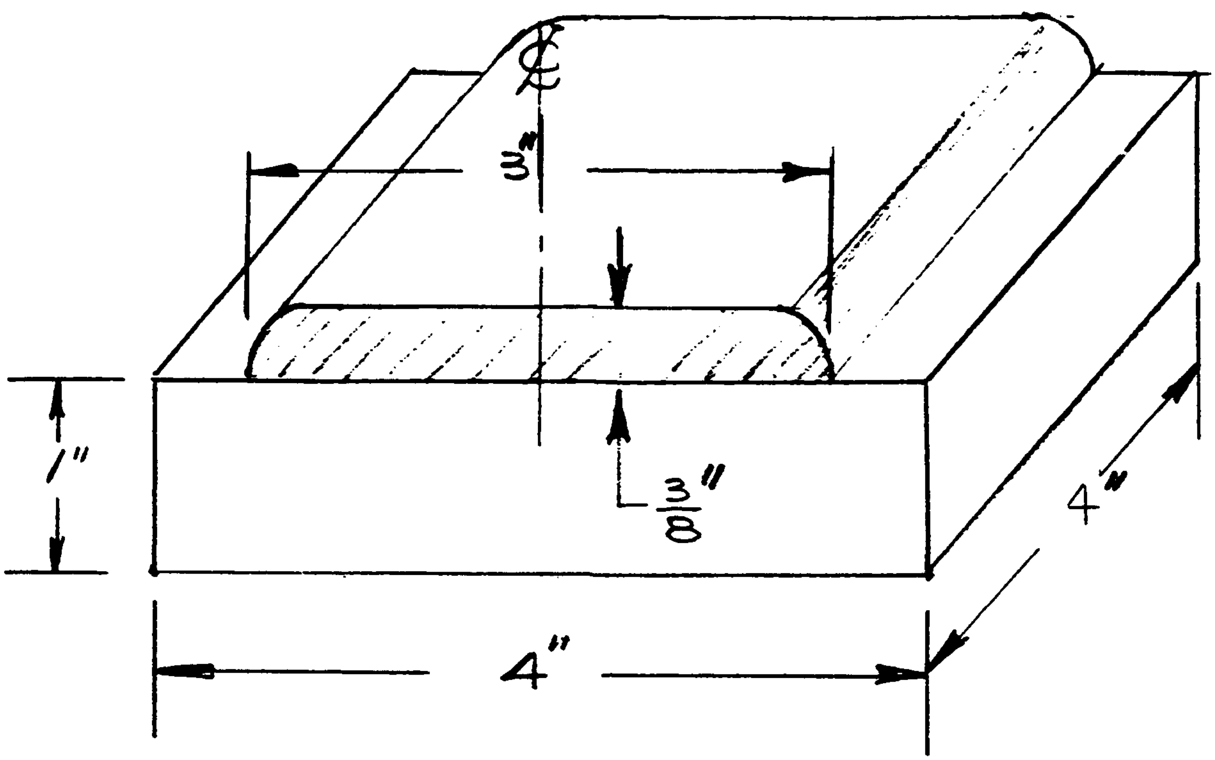

Figure 6a. Schematic of 4 x 4 x 1-inch annealed 4140 test specimen.

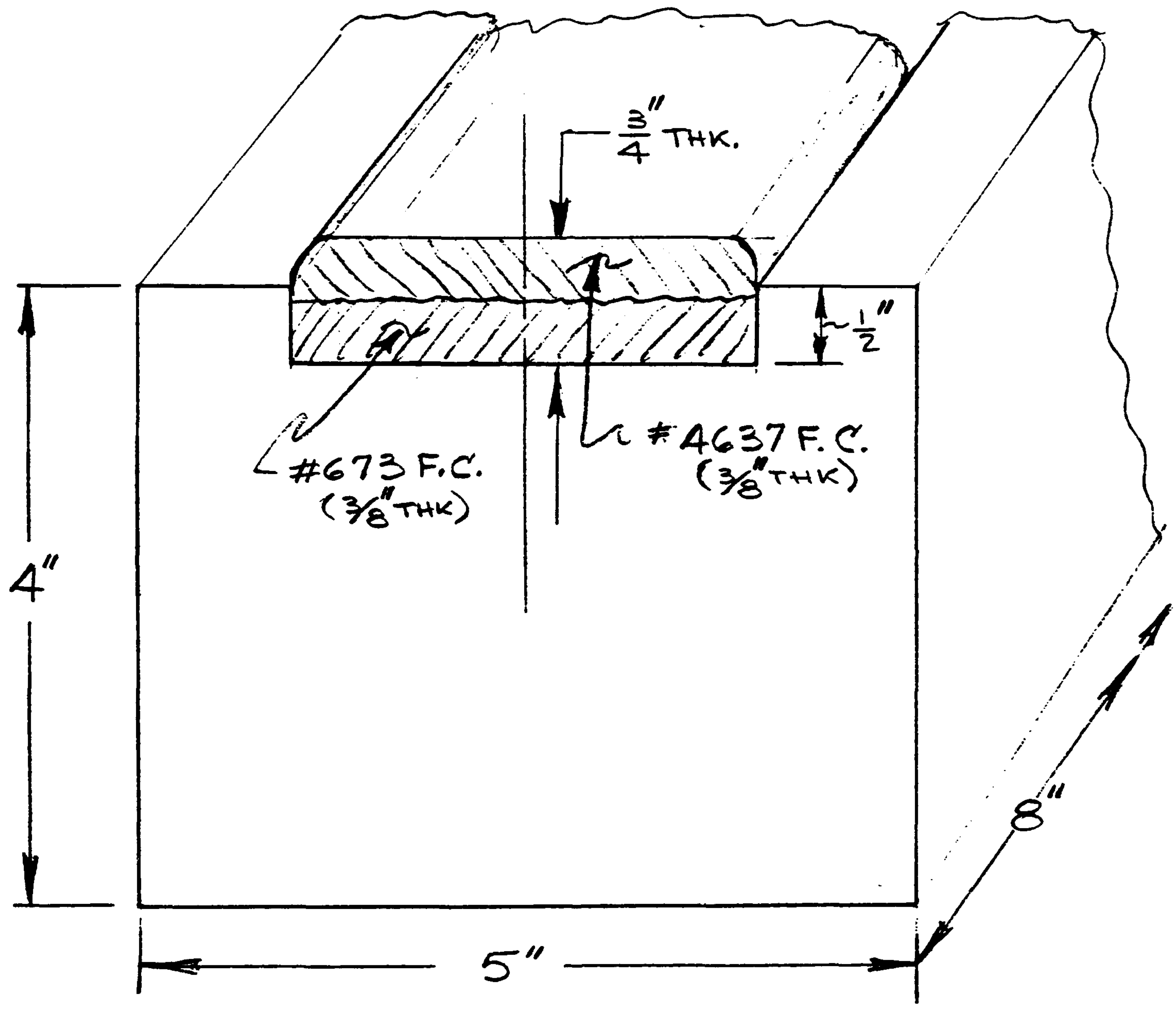

Figure 6b. Schematic of 4 x 5 x 8-inch annealed 4140 test specimen.

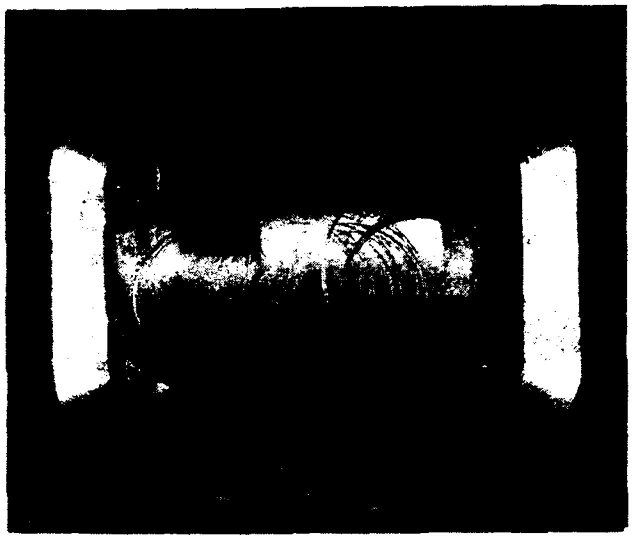

Figure 7. Top view of 4 x 5 x 8-inch test specimen showing machined weld prep to be filled with required hardfacing materials.

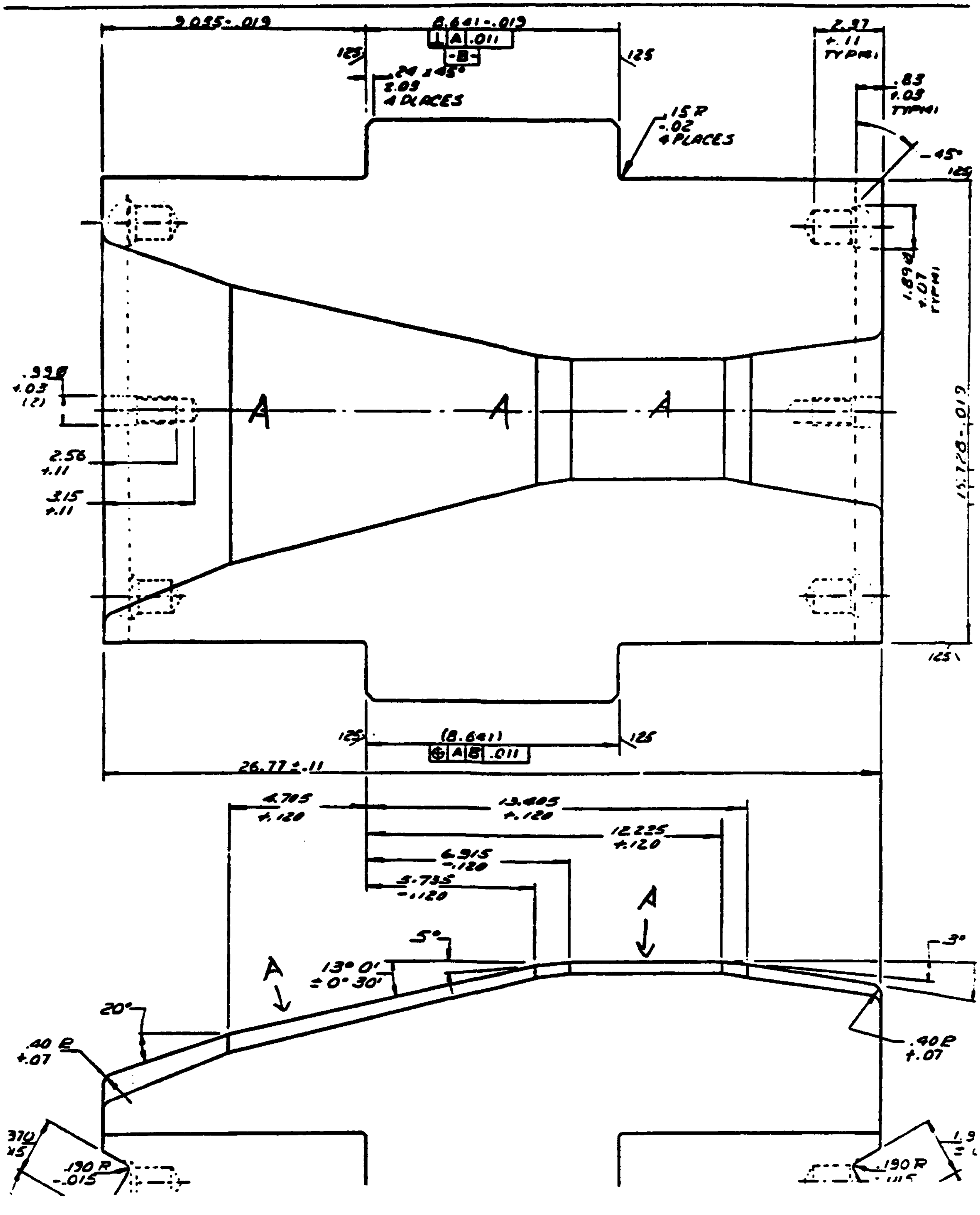

Figure 8. Top and side schematic views, respectively, of forging hammers.
The A's represent the area to be welded.

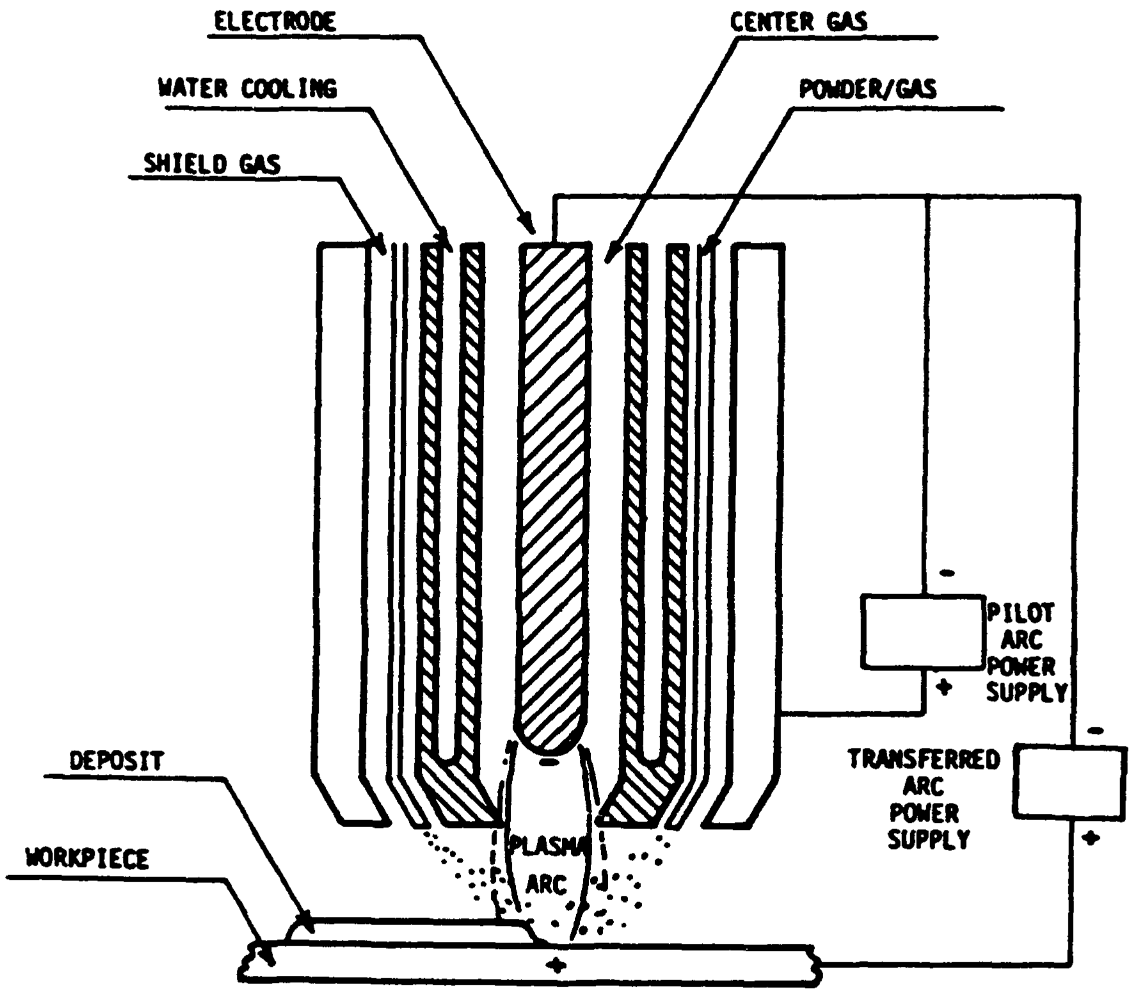

Figure 9. Schematic of PTA torch assembly.

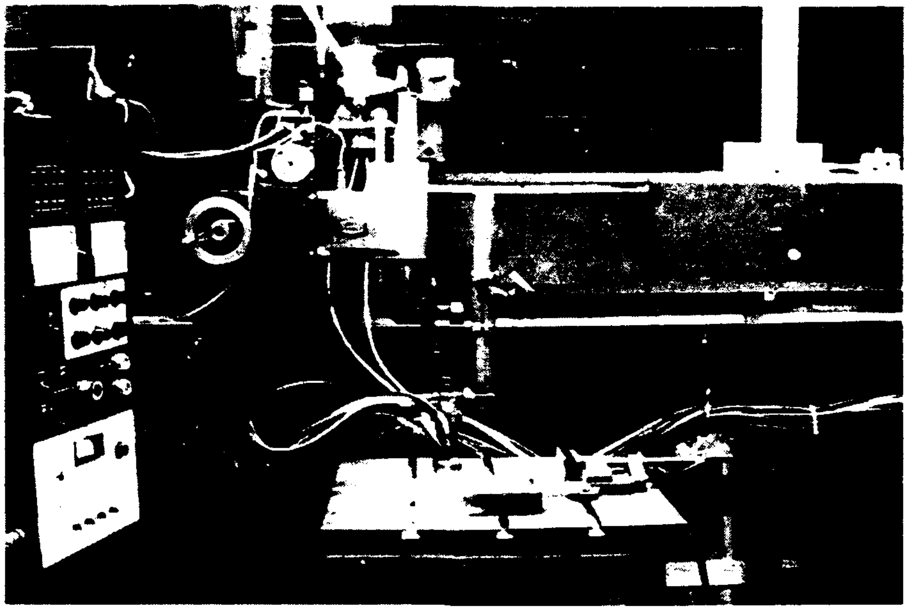

Figure 10. Overall view of PTA equipment setup.

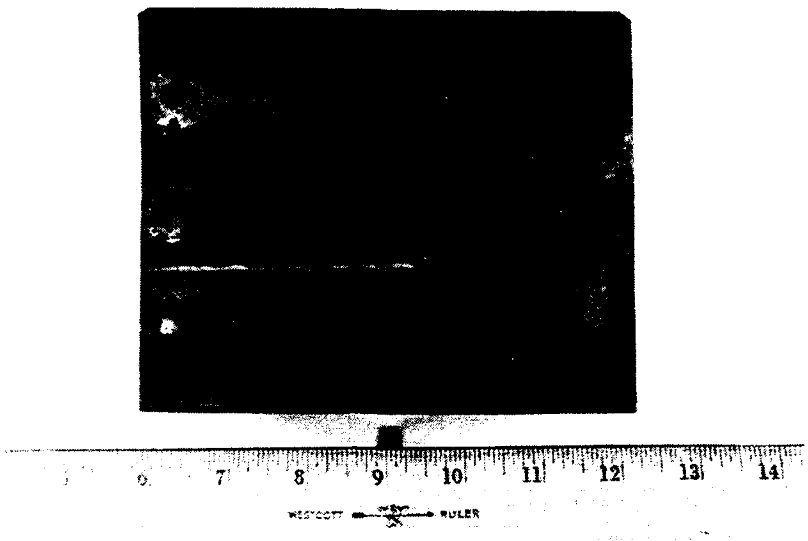

Figure 11. PTA powder welded test specimen showing smooth, clean weld deposits.

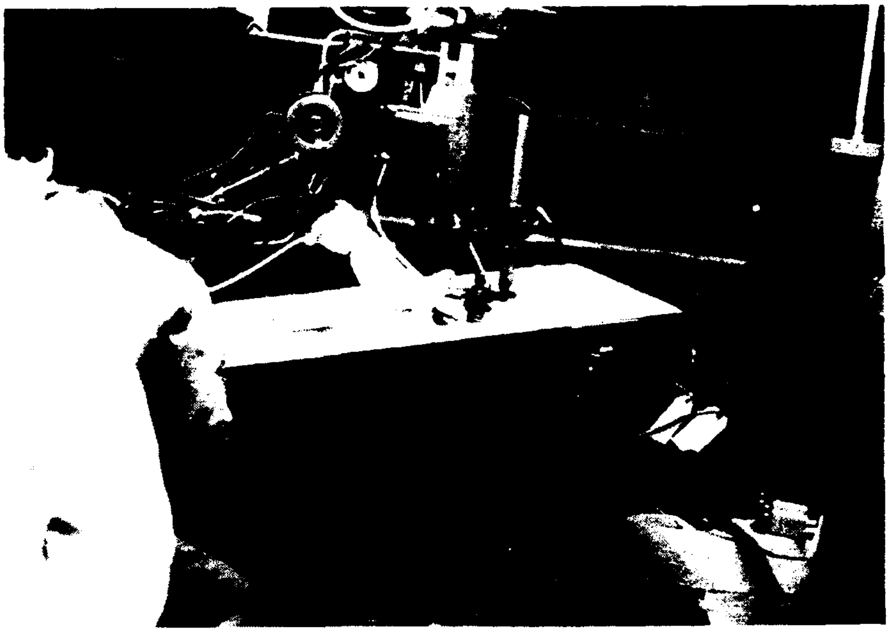

Figure 12a. Equipment setup used for weld repair of hammers.

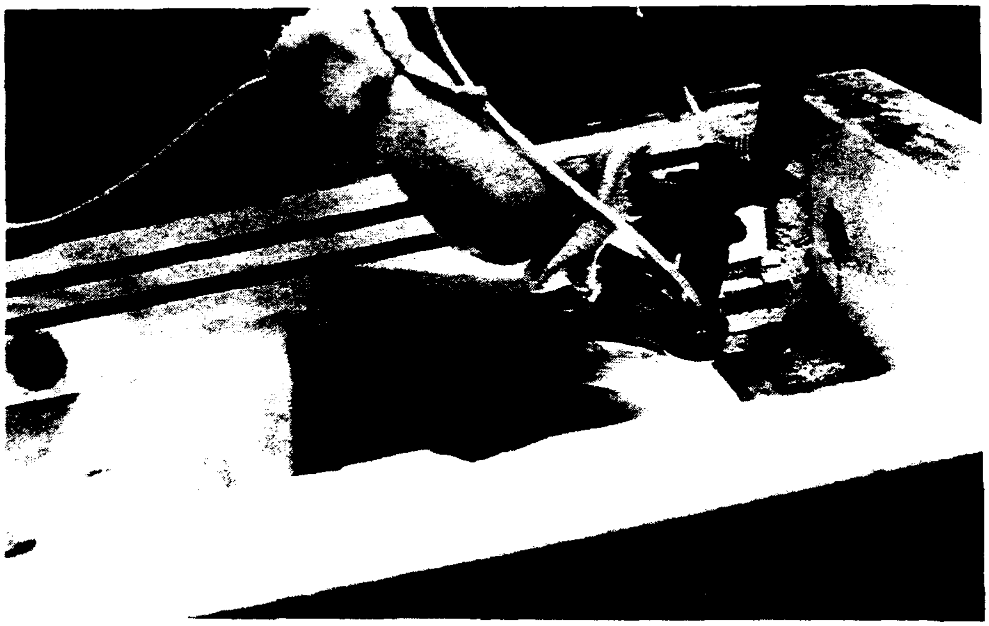

Figure 12b. PTA torch shown traversing over forging hammers.

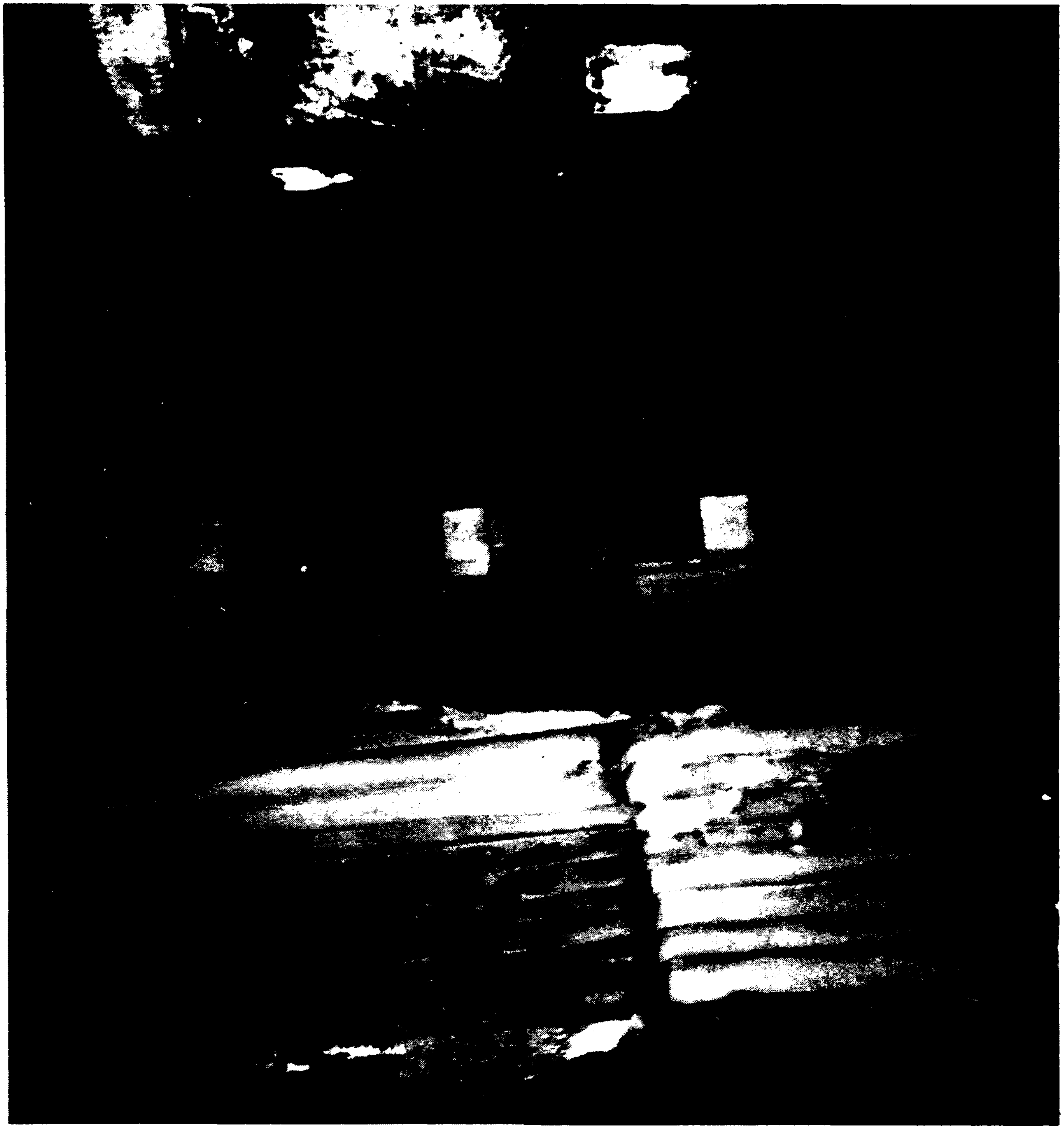

Figure 13. PTA as-welded forging hammer.

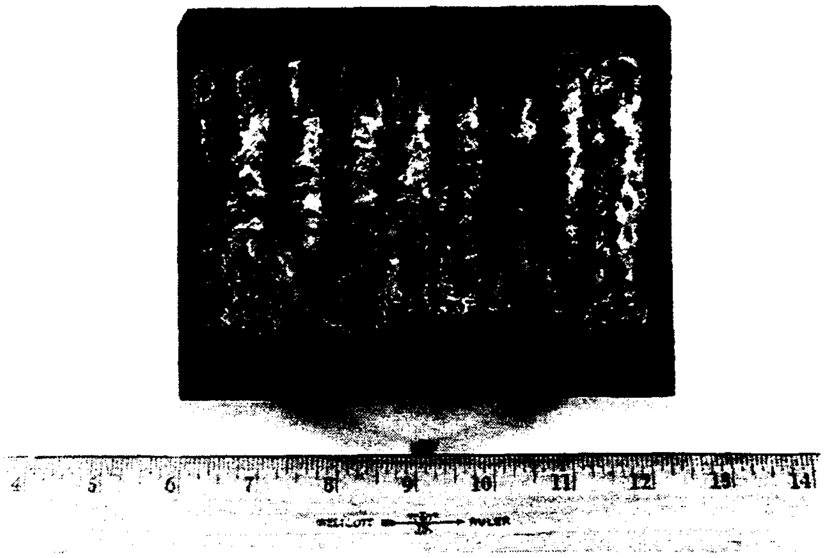

Figure 14. MIG as-welded 4 x 5 x 8-inch test specimen showing rough deposits.

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